# *JPAnalytics*

*Where Data, Theory, and Analysis Create Innovative Solutions*

August 5, 2016

Dr. Robert Headrick
ONR Code: 332
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

Dear Dr. Headrick,

Attached please find the progress report for ONR Contract N00014-14-C-0230 for the period of April 20, 2016 to July 19, 2016.

James C. Preisig
President, JPAnalytics LLC

CC: DCMA Boston
DTIC
Director, NRL

# Progress Report #9

## Coupled Research in Ocean Acoustics and Signal Processing for the Next Generation of Underwater Acoustic Communication Systems

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|---|---|
| Principal Investigator's Name: | Dr. James Preisig |
| Period Covered By Report: | 4/20/2016 to 7/19/2016 |
| Report Date: | 8/5/2016 |
| Contract Number: | N00014-14-C-0230 |
| Firm Name and Address: | JPAnalytics LLC<br>638 Brick Kiln Road<br>Falmouth, MA 02540<br>jpreisig@jpanalytics.com<br>(508) 566-0236 |
| Program Officer: | Dr. Robert Headrick<br>ONR Code: 322<br>Office of Naval Research<br>875 North Randolph St.<br>Arlington, VA 22203-1995<br>Robert.Headrick@navy.mil |
| Security Classification: | Unclassified |
| Distribution Statement: | Approved for public release. Distribution is unlimited. |
| Total Contract Amount: | $595,731 |
| Costs Incurred This Period: | $47,566.50 |
| Costs Incurred To Date: | $360,490.05 |
| Estimated Costs To Complete: | $235,240.95 |

1. **Description:** Technical work this period has spanned two areas. The primary of these was the continued development and convergence analysis of new methods of applying reduced-dimensional inference algorithms to improve the performance of or reduce the computational complexity of coherent equalizer adaptation algorithms. In this time period, the development of two classes of algorithms was finalized. The first class was an Expectation Maximization (EM) based technique which used unobserved "intermediate" variables to break a high-dimensional estimation problem such as least-squares (LS) optimization of a large equalizer filter vector into a parallel but coupled set of low-dimensional problems. This technique is termed Graphical Expectation Maximization - Least Squares (GEM-LS). The estimator is iterative and the work in this time period focused on characterizing the convergence properties of this algorithm and evaluate its performance using various iteration stopping criteria. The second class of algorithms was a recursive approximation of the GEM-LS approach by relaxing the statistical assumptions which is termed the Relaxed Approximate Graph-Structured Recursive Least Squares (RAGS-RLS). This work comprised the final portion of the thesis research of MIT/WHOI Joint Program student, Atulya Yellepeddi and was motivated by the desire to exploit lower dimensional structures in acoustic communications data, specifically frequency domain transformations of received communications signals, to achieve the specified improvements. Atulya successfully defended and submitted his PhD thesis in June. This work falls under Research Task 3 from Section 2.2 of the Technical Approach and Justification.

   The second area of work is that of characterizing the performance of adaptive equalizers in order to evaluate different system configuration trade-offs with respect to their impact on communications performance and ease of implementation. Work in this time period included two thrusts. One was combining analysis using time-invariant asymptotic Random Matrix Theory (RMT) with data generated by an acoustic communications simulator based upon the PC-SWAT numerical acoustic propagation model to analyze the physical configuration of underwater acoustic communications systems. The second thrust was investigating methods of extending time-invariance RMT to handle time-varying environments. This work falls under Research Task 1 from Section 2.2 of the Technical Approach and Justification of the contract proposal.

2. **Major Accomplishments this Period:** The major technical accomplishment this period was the wrapping up of Atulya Yellepeddi's work on reduced dimensional inference algorithms, demonstration of the GEM-LS and RAGS-

RLS algorithms and the successful defense of his thesis in the MIT/WHOI Joint Program.

3. **Results and Recommendations:**

The development and analysis of the RAGS-RLS and GEM-LS algorithms was concluded. Figure 1 shows the performance of the RAGS-RLS algorithm processing communications data collected at 200 meters range during the SPACE08 field experiment. These results were generate with an equalizer utilizing 4 receive array channels and are averaged over a number of signal periods spanning a wide range of weather conditions. The equalizer soft decision error in dB is shown as a function of received in-band SNR (note, the baseband received signals are artificially degraded in SNR by adding baseband received noise recorded when no signals were being transmitted). The 4 RGS-RLS curves show the algorithm with 4 levels of dimensionality reduction (d = 1 is the lowest dimension model, d = 4 is a higher dimension model). The blue curve shows the performance of an equalizer using the traditional RLS algorithm while the red curve shows the performance of an equalizer using the normalized least mean squares (N-LMS) algorithm. Not that, particularly at lower SNRs, all of the RAGS-RLS algorithms marginally outperform the conventional RLS algorithm. In addition, the computational complexity of the RAGS-RLS algorithms is significantly less than that of the conventional RLS algorithm For example, the d=1 RAGS-RLS algorithm has a computational complexity of one twenty fifth of the complexity of the conventional RLS algorithm.

Figure 2 shows the performance of the GEM-LS algorithm in comparison the both conventional and diagonally loaded LS algorithms and a basis pursuit algorithm (BPDN). The two instances of the GEM-LS algorithm correspond to two different iteration stopping criteria. The received signal data used for this test was generated with a PC-SWAT propagation model for a shallow water environment similar to that of the SPACE08 experiment. The channel impulse response being estimated is 125 taps in length and the error in the prediction of the channel impulse response (in dB) is shown as a function of $N$, the number of signal observations. Note that the performance of the GEM-LS algorithm degrades smoothly as the number of observations is reduced, even in the "under determined" regime of N¡125. The computational complexity of the GEM-LS algorithm is not more than that of the conventional and diagonally loaded LS algorithms and significantly less than that of the BPDN algorithm. In addition, the structure of the GEM-LS is highly parallel and can

therefore be implemented efficiently on multi-core parallel processing hardware architectures.

Outstanding issues with the algorithms include a proper scaling of update steps of the RAGS-RLS algorithm and developing a data-driven stopping criterion for the iterations of the GEM-LS algorithm. Further research into these two aspects of the algorithms will greatly enhance their potential applicability in practical systems.

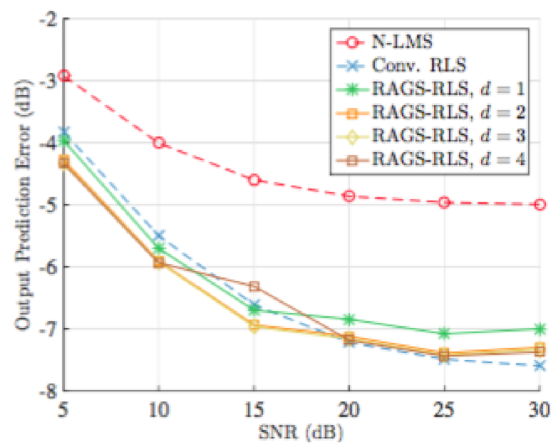


Figure 1: RAGS-RLS Channel Equalization Soft Decision Error - 200 meter range - 4 channels

4. **Publications and Presentations:** This period, the author attended and gave a ”community service” presentation at the 171st Meeting of the Acoustical Society of America in Salt Lake City, UT.

   J. Preisig, “Signal processing: Ubiquitous In acoustics”, at *171st Meeting of the Acoustical Society of America*. Salt Lake City, UT,, May 23 - 27, 2016.

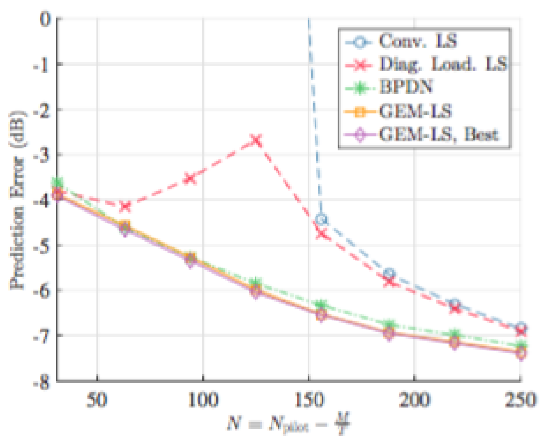


Figure 2: Channel Estimation Performance of GEM-LS, LS and Basis Pursuit Algorithms on Simulated Data (5 dB SNR)